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ABSTRACT

Recently, confirmatory factor analysis has been extended to the case of dichotomous data (e.g., Muthen, 1978). In this study, confirmatory factor analysis was applied to all-or-none recall data from a designed experiment. In the experiment, subjects read pairs of English nouns and then tried to recall the right hand member of the pair when presented with the left hand member. The retention interval was varied within-subjects. Factor analyses treating the within-subject factor as separate variables failed to confirm a unidimensional view of memory. Instead, a distinction between short- and long-term memory was necessary to account for the data. The proposal of Atkinson and Shiffrin (1968), in which memory is held to consist of two separate storage systems, was supported. (Author)

Factor Analysis of Dichotomous Memory Items from a Designed Experiment

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Factor Analysis of Dichotomous Memory Items from a Designed Experiment

Recently, a number of noteworthy attempts have been made to bridge the gap between information-processing theories and psychometric techniques, for example, Geiselman, Woodward, & Beatty (1982). Confirmatory factor analysis, and other models with latent variables, are most typically applied to data sets in which random assignment of subjects to levels of the independent variables has not been applied, or is impossible (cf. Bentler & Woodward, 1978; Hunt, Lunneborg, & Lewis, 1975). It is certainly not the case that the randomization possible in the laboratory is incompatible with factor analytic and related methodologies. In fact, whenever randomization or other physical control is not imposed, model specification is always hostage to "the missing variable" problem. Randomization, on the other hand, ensures that any missing variable is uncorrelated with the variable subject to random assignment. Conclusions attending a good fit for the nonmissing variables in the model are thus strengthened. Combining the power of randomization with the sophistication of latent variable modelling would seem to be highly promising.

In repeated measures experiments on memory, each subject often views or listens to a pair of items that are then tested by cueing one member of the pair with the other. The items to be recalled are often verbal such as English words. For a given subject, all items representing the same treatment cell are usually summed, and the summed scores are submitted to analysis of variance. In many instances, the traditional analysis is adequate and justified. However, potentially valuable information pertaining to individual items is lost under such a procedure.

Another potential liability lies with the use of unit item weights inherent to the summing procedure. Any particular item is a flawed indicator of the mental events underlying the treatment effect of interest. It is possible that some items are more highly correlated with the psychological processes involved in memory than are other items. Giving each item equal weighting is then suboptimal. Under some conditions, summed scores may not even be in the correct order (Muthen & Christofferson, 1981).

Also, it is possible to do real violence to tests of certain hypotheses when the observed summed scores for treatment conditions are a monotone but nonlinear transformation of the underlying psychological process of interest. But polynomial trend and some questions of interaction require that the data be measured at the interval or ratio level.

Factor analytic methodology is one way to circumvent these problems.

Experiment I

In the usual scheme of things in memory research, counterbalancing techniques are applied which make for dependencies between subjects. In contrast, experiment I was designed so that all differences between subjects in the same treatment group are purely differences between the ability of those subjects to memorize. Each of these subjects experienced the same sequence of verbal items, and presentation and test events.

The ability of subjects to memorize might be represented on a single ability dimension. A subject with good memory skills would find all but the hardest word pair in the hardest experimental condition easy to recall, while a subject with limited memory ability would be taxed by easy word pairs in easy experimental conditions. Such a one dimensional view of memory has been propounded by a number of individuals, including Wickelgren and Norman (1966) and others.

There are alternatives to a purely unidimensional view of memory. Atkinson and Shiffrin (1968) and others have hypothesized that memory has two subsystems: a long-term store (LTS) and a short-term store (STS). Whether memory can be considered a unidimensional system was investigated with the general k-dimensional factor analysis model for dichotomous indicators (Christofferson, 1975, Muthen, 1978; Muthen and Christofferson, 1981). The model assumes a normal distribution of subject ability, and assumes that each pair of dichotomous items are the realization of two underlying continuous variables distributed according to the bivariate normal density function. These assumptions are tenable for memory data of this kind (Hofacker, Note 1).

In essence, this model posits a factor analysis structure for the tetrachoric correlations among the items,

$$\Sigma^* = \Lambda\Psi\Lambda' + \Theta.$$

The notation here is from Muthen (Note 2).

In the experiment, 251 subjects flipped through IBM cards at a 10.1 second rate. Some of the cards presented a new pair of words to be memorized. Other cards showed just the left hand word and the subjects task was to write in the right hand word. Each subject recieved two decks. In the first deck, 24 presentations and 12 tests were mixed in a planned sequence. Tests occured after 0, 1, 3, or 6 intervening list events. For example, lets look at the lag 1 condition. Say the current card shows the pair FROG-PLUM. The next card may present or test some other pair, such as DUNE-WISH. The card after that shows the word FROG and the subject is to write in the word PLUM. Twelve of the pairs were not tested until after a 20 minute filler activity, at which time the second deck was passed out which consisted of the 12 remaining tests.

There were two independent groups of subjects with different words and a different sequence of conditions.

Seven items were picked for the factor analysis investigations. Items were picked for the factor analysis in order to include a mix of short, middle, and long retention intervals. Two items were picked that were tested after a lag of one item, one was chosen that was tested after a three item lag, two were chosen that were tested after six items, and two were chosen that were not tested until the second card deck. No item could be included in the model that had too high a cued recall score. The reason for this is that a zero cell in any two way marginal table for any pair of items makes it impossible to calculate the variance of that proportion, a quantity needed for goodness of fit tests. The problem of zero cells made it impossible to use any zero-lag items, and impossible to use more than one three-lag items.

Four hypothesized underlying structures were tested with these items. According to the first structure, the relationship among all seven items can be accounted for by a single latent continuum. The relationship between this continuum and the underlying memorability values for each item is the same. The hypothesis is illustrated as a

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Insert Figure 1 about Here

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path diagram in Figure 1. Under the hypothesis, only one parameter needs to be included to model the correlations among the y^* variables, $\lambda = \lambda$ for all i. The first hypothesis is closely related to Rasch's (1966) model.

The second structure allows for different slopes of the regression of memorability of the item on the single dimension of latent ability. One of the factor loadings in Λ needs to be set to 1.0 in order to tie down the metric of the unobserved η variable. When a loading is fixed like this, the variance of the factor becomes a free parameter. In this model, there are six loadings and one factor variance to be estimated from the data.

The third hypothesis posits a distinction between STS and LTS. A list event is either dependent on STS or LTS but not both (Tulving and

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Insert Figure 2 about Here

Colatla, 1975). The path diagram for the model is given in Figure 2. If the cue for a list event is given after three or less intervening items or tests, then the item is retrieved from STS. Otherwise, the item is retrieved from LTS. In the model pictured in Figure 2, there are five parameters in Λ, plus two factor variances and one factor covariance to be estimated.

The fourth hypothesis is a more general alternative in which there is a distinction between STS and LTS, but any item can be dependent on either to various amounts. The other four models are special cases of this model. The model is unrestricted in the sense that just enough fixed elements have been entered into Λ and Ψ to identify a two factor structure. The Λ matrix can then be rotated by an algorithm such as PROMAX, which tries to create a simple pattern in Λ. In general, to make the model "just identified", k^2 fixed elements have to be entered into Λ and/or Ψ, where k is the number of factors (Joreskog, 1970). Following the convention of unrestricted factor analysis, the factor variances are fixed at unity, allowing the covariance among the factors to be interpreted as a correlation. In the model, there are 14 distinct elements in Λ and three in Ψ, so subtracting 2^2 yields 13 parameters to be estimated.

Insert Table 1 about Here

The pattern of results is given in Table 1. The degrees of freedom for any model can be calculated by noting that there are seven observed variables with [7 * (7 - 1)] / 2 = 21 tetrachoric correlations to account for. The degrees of freedom for any model are then 21, less the number of estimated parameters.

For group A, the conclusion is straightforward. The only model to fit the pattern of tetrachoric correlations among the seven items is the general STS/LTS model. All other models must be rejected. In group B, the model of exclusive STS/LTS, and the unidimensional model also fit the data. However, it is well known that the difference between chi-square test statistics is itself distributed as chi-square with degrees of freedom equal to the difference in degrees of freedom if one model can be expressed as a special case of the other model. For group B, we find that the difference between the exclusive STS/LTS model and the general STS/LTS model has a chi-square value of 11.474 with five degrees of freedom, $p = .043$. The conclusion for both groups will then be the same: The preferred model is the general STS/LTS model. PROMAX factor loadings and the factor correlation for the model are given in Table 2. The pattern of loadings is generally consistent with the hypothesis of a

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Insert Table 2 about Here

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short-term memory system related to short lags, and a long-term system related to long lags. For both groups, a high loading on one factor is usually associated with a low or even negative loading on the other. Such a pattern is consistent with the idea that STS processing is not compatable with LTS processing.

Interestingly, in both groups a positive correlation exists between STS and LTS factors. A positive correlation would indicate that the two factors probably represent two distinct abilities of subjects and not propensities to use one of the two stores. It seems likely that ability to use STS would positively correlated with the ability to retrieve from LTS. If the two factors represented propensities to use either STS or LTS, we might expect a negative correlation.

The pattern of results suggests a fifth model, in which some compromise is made between the exclusive and general STS/LTS models. Items at the medium lags of three and six are now held to be output from either STS or LTS or both. In this sense the compromise model is the same as the general STS/LTS model. Items at lag 1 and items tested after 20 minutes are held to be exclusively output from STS or LTS,

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Insert Figure 3 about Here

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respectively. The compromise model is pictured in Figure 3. As can be seen in the figure, the compromise model has three more λ parameters than does the exclusive STS/LTS model. For group A, the model fits with a chi-square value 13.878 on 10 degrees of freedom, $p = .179$. The comparable figures for group B are $\chi^2 = 13.122$, $p = .217$. For group A, the difference in chi-square between the general STS/LTS model and the compromise model is 8.067, which has a probability of .018 on two degrees of freedom. For group B, the difference is 9.667, $p = .008$. The general model fits reliably better in both groups. One possible reason for this would be that an item at short lags is sometimes output from LTS.

The conclusions one can draw from these factor analyses are as follows. Overall, the data offer strong support for the validity of the distinction between LTS and STS. Despite the admittedly low power of the chi square in such small samples, unidimensional models were rejected outright in group A, and barely fit in group B. In group B, chi square was significantly reduced when the more general two factor model was fit.

Experiment II

~~In Experiment I the~~ verbal item was confounded with ~~the list~~ event in all its context. Experiment II was designed to do exactly the opposite. In Experiment II, the sequence of particular verbal items for each subject was unique. The variance within any experimental condition was then a mixture of between-item and between-subject differences.

Subjects participating in Experiment II were 112 undergraduates at the University of California, Los Angeles. As was the case with Experiment I, each subject had a deck of IBM cards. Each subject's deck contained a unique sequence of particular verbal items. The experimental sequence of conditions was nearly identical for each subject, but the actual verbal pair used was randomaly drawn from a pool consiting of 133 word pairs.

The following points along the retention function were chosen to be representative of memory retention: 1, 2, 3, 7, 20, 22, 24, and 28 card

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Insert Table 3 about Here

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lags. The results of the analysis are given in Table 3. As in Experiment I, the simple Rasch-like model must be rejected out of hand. For the remaining models, all of which cannot be rejected given a sample of 112 subjects, the difference between the unidimensional model and the model of exclusive STS/LTS items generates a chi-square value of 4.72 on 1 degree of freedom, $p = .030$. Again, it can be concluded that including long-term and short-term factors account for the tetrachoric correlations better than a single memorability factor. Also, the exclusive STS/LTS model seems to hold its own against the general STS/LTS model. The difference in chi square values for the two models is 9.013, which, on two degrees of freedom has a probability of .173.

Conclusions

One of the main proposals of this paper is that to understand memory phenomena, recourse to unobserved variables is necessary. The results of experiments I and II make a strong case for the existence of two mental structures closely tied to the length of the retention interval.

The current approach bears some similarity to Markov process modelling as well. In the Markov chain approach to memory theorizing, observed trial to trial probability of recall is considered a manifestation of latent states of the subject. In the current approach, the latent space is held to be continuous. The difference lies in the current reliance on differences between individual subjects. The approximation of subject abilities or propensities to a continuous space of small dimensionality is reasonable even while the memorability of individual verbal items may well be discrete.

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Table 1

Tests of Models for Experiment I

		Model			
Group		Rasch	One Dimension	Exclusive STS/LTS	General STS/LTS
	df	20	14	13	8
A (n=125)	Chi-square	41.080	32.720	31.634	5.811
	p	.004	.003	.003	.668
B (n=126)	Chi-square	39.178	22.579	14.929	3.455
	p	.006	.067	.312	.903

Table 2

Parameter Estimates for the General STS/LTS Models

	Lag	Group A		Group B	
	1	1.367	-.054	.927	-.371
	1	.229	.535	.590	.227
Factor	3	.218	.449	.462	.260
Loadings	6	-.190	.726	-.245	.826
	6	.039	.848	.688	.105
	20 Min.	-.038	.648	-.016	.750
	20 Min.	-.060	.903	-.245	.748
Factor		1.000		1.000	
Covariances		.407	1.000	.304	1.000

Table 3

Model Tests and Parameter Estimates for Experiment II

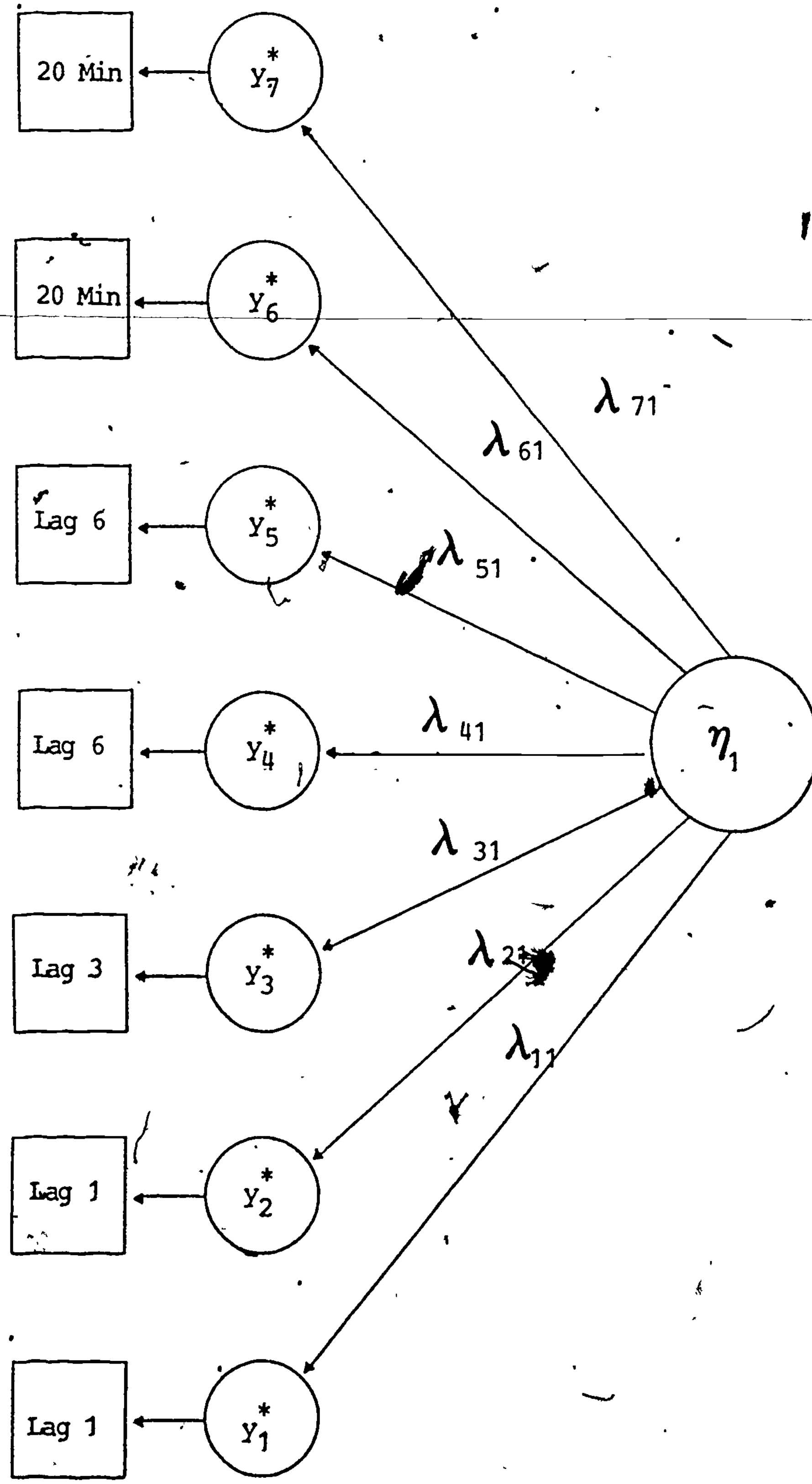
			Model				
	Lag	Rasch	One Dimension	Exclusive STS/LTS		General STS/LTS	
Chi-square		40.947	21.402	16.678		7.665	
p		.042	.374	.612		.865	
df		27	20	19		13	
	1	.677	1.000	1.000	0.000	.899	-.189
	2	.677	1.621	1.485	0.000	.403	.383
Factor	3	.677	2.018	1.988	0.000	.309	.542
Loadings	7	.677	2.072	0.000	1.000	-.265	.896
	20	.677	1.807	0.000	0.861	-.088	.712
	22	.677	2.185	0.000	1.049	.003	.757
	24	.677	2.278	0.000	1.081	.181	.662
	28	.677	1.781	0.000	0.864	.129	.581
Factor		1.000	.134	.196		1.000	
Covariances				.262	.546	.458	1.000

Figure Captions

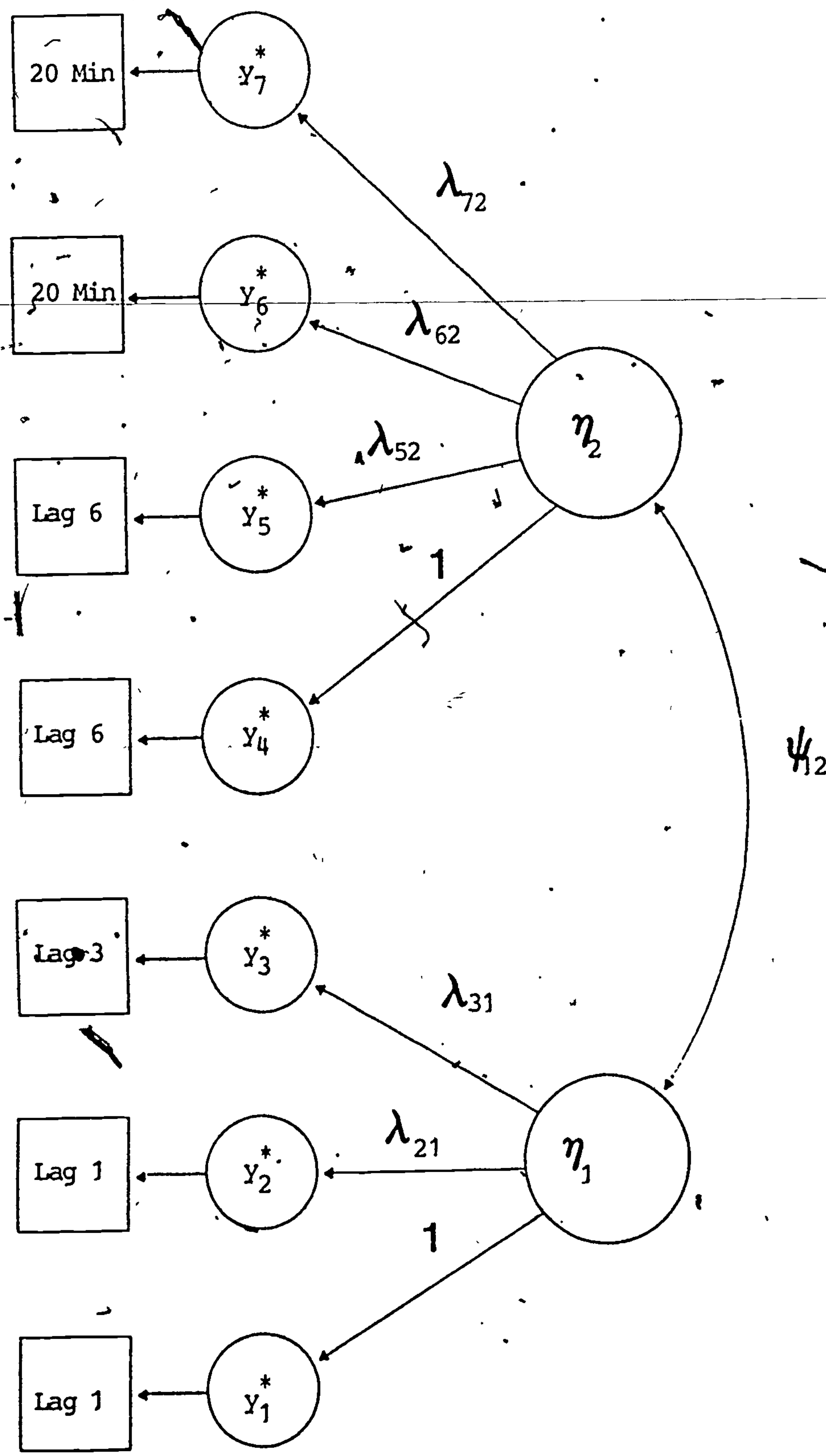
Figure 1. Path diagram for the unidimensional model.

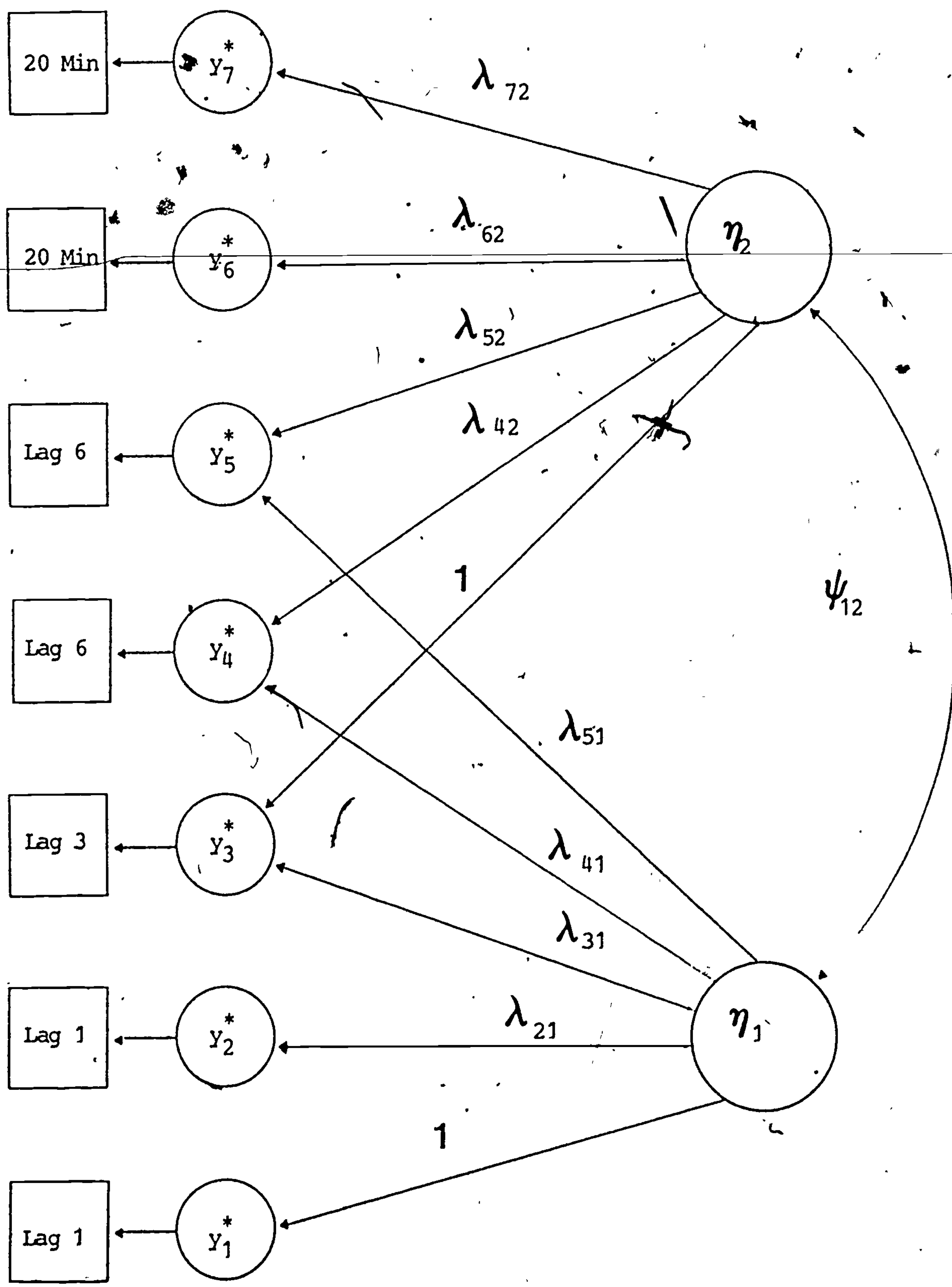
Figure 2. Path diagram for the exclusive STS/LTS model.

Figure 3. Path diagram for the compromise STS/LTS model. Items at lags of 1 and 20 Min. are output exclusively from STS or LTS. Items at lags of 3 and 6 can be output from either store.



20 Min
20 Min
Lag 6
Lag 6
Lag 3
Lag 1
Lag 1
y_7^*
y_6^*
y_5^*
y_4^*
y_3^*
y_2^*
y_1^*
λ_{71}
λ_{61}
λ_{51}
λ_{41}
λ_{31}
λ_{21}
λ_{11}
η_1


20 Min
20 Min
Lag 6
Lag 6
Lag 3
Lag 1
Lag 1
y_7^*
y_6^*
y_5^*
y_4^*
y_3^*
y_2^*
y_1^*
λ_{72}
λ_{62}
λ_{52}
1
λ_{31}
λ_{21}
1
η_2
η_1
ψ_{12}


20 Min
20 Min
Lag 6
Lag 6
Lag 3
Lag 1
Lag 1
y*7
y*6
y*5
y*4
y*3
y*2
y*1
λ72
λ62
λ52
λ42
1
λ51
λ41
λ31
λ21
1
η2
η1
ψ12

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ABSTRACT

Recently, confirmatory factor analysis has been extended to the case of dichotomous data (e. g. Muthen, 1978). In this study, confirmatory factor analysis was applied to all-or-none recall data from a designed experiment. In the experiment, subjects read pairs of English nouns and then tried to recall the right hand member of the pair when presented with the left hand member. The retention inverval was varied within-subjects. Factor analyses treating the within-subject factor as separate variables failed to confirm a unidimensional view of memory. Instead, a distinction between short- and long-term memory was necessary to account for the data. The proposal of Atkinson and Shiffrin (1968), in which memory is held to consist of two separate storage systems, was supported.

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